**Power Tip 27: Paralleling power supplies using the droop method**

*Robert Kollman, Texas Instruments* - September 01, 2010

(Editor's Note: To see a linked list of all entries in this series, click [here](#).)

(April 2011: We've updated this Power Tip to include a video by the author; you can see it at the bottom)

In this **Power Tip**, we will look at a simple method to parallel supplies. Some of the key care concerns when paralleling supplies are:

1) no single point failures added by the droop circuit;
2) as a corollary to #1, no master-slave operation;
3) minimum interconnect;
4) no adverse impact on efficiency;
5) good voltage regulation; and
6) preserved load dynamics.

The droop method provides a simple way to meet many of these requirements. It works by allowing the power output voltage to sag as a function of load current. As shown in **Figure 1**, paralleled power supplies tend to equalize output currents because of this load line.

![Figure 1: Drooping power supply output voltage enables current share.](#)

This figure shows the output voltage versus load characteristics of three power supplies. Because of
component tolerances, the three power supplies have slightly different V-I characteristics. For a given load condition, a horizontal line represents the output voltage when all three supplies are connected in parallel. The intersections of the horizontal line with the load lines represent the output currents of the individual supplies. This method obviously degrades the system voltage regulation.

There is a trade-off between how well the currents balance and the voltage regulation. The first step of this trade is to determine the regulator tolerance; i.e., how far does the worst case design depart from the nominal. The important items to establish are reference accuracy over temperature and divider tolerance (see Power Tip 18).

While how close to nominal you can set your output voltage by picking resistors that affect your accuracy, it will not impact the current share. You then are ready to pick either your slope or your allowable deviation, and calculate the other. If you assume that the slope is relatively constant, the variables are simply related as:

\[
\frac{2 \times SPA}{D} = LE
\]

Where:
- SPA = Set point accuracy in percent
- D = Voltage droop from no load to full load in percent
- LE = Load extreme or how far the loads could be off, in percent

In doing the calculations, you will find the short coming of this method. It takes extreme accuracy in setting the output voltage and significant voltage droop to get a reasonable current share. For instance, as shown in Figure 1, with 3.5% tolerances and 20% voltage droop, you can have 35% current mismatch. This amount of droop may be acceptable in high-voltage systems, but will not be in low-voltage supplies.

The first thought about implementing voltage drop might be to put a big resistor in series with the output voltage, until you look at the tolerance issues and the resulting losses. In our previous example, we would loose over 20 percent of the output power in this resistor.

The next thought is to measure the output current of the power supply, amplify and use this measurement to offset the output voltage setting circuit. This works for voltage mode control, but with current mode control, a much simpler method is available. By limiting the DC gain of the control loop, you have built a synthetic resistor. Appendix 1 below (after the About the Author box) goes through the simple math for calculating the output impedance based on Figure 2.

The result is that the output impedance of this system is equal to the negative inverse of the compensator gain, times the power stage gain. Most power supplies contain an integrator in the
compensation, which results in a very large DC compensator gain. By adjusting the DC gain to a
specific value, a desired droop can be obtained. Usually this is quite easy to implement, just add a
resistor across the error amplifier.

Figure 2: Voltage droop is easily implemented with current mode control.
(Click on image to enlarge)

Please join us next month when we will discuss tips for hot swap controllers.

For more information about this and other power solutions, visit: www.ti.com/power-ca.

About the author

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Appendix 1

\[ V_o = (V_{ref} - V_o) \cdot K \cdot G \cdot R_l \]

\[ R_l = \frac{V_o}{I_o} \]

\[ V_o = (V_{ref} - V_o) \cdot K \cdot G \cdot V_o / I_o \]

\[ V_{ref} - V_o = \frac{I_o}{K \cdot G} \]

\[ V_o = V_{ref} - \frac{I_o}{K \cdot G} \]

\[ \frac{\partial V_o}{\partial I_o} = \frac{-1}{K \cdot G} \]